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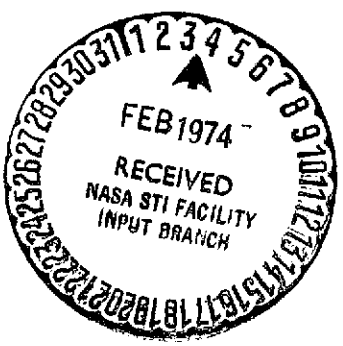

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Lunar Surface Chemical Composition in the Region of the Activity of "Lunokhod 2"

by

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Abstract

Results of investigations carried out by means of spectometer RIFMA-M give evidence for the discovery of gradual changes of the lunar surface chemical composition in the transit zone "mare-highland" along the route of "Lunokhod-2" on the bottom of Crater Le Monnier, in the highland region and in a zone of tectonic fracturing.

The present paper is devoted to the analysis of the experimental results 3
generated by means of the modernized Roetgen spectrometer "RIFMA-M", installed on "Lunokhod 2". In construction of a modernized variant of the spectrometer the test of the operation of the apparatus on "Lunokhod 1" (1-3) and the specifications of the scientific tasks of "Lunokhod 2" were taken into account.

As is shown in Table 1, which contains data concerning the composition of the lunar surface in the mare ("Luna 16") and the highland ("Luna 20") regions, the highlands are characterized by higher percentages of Al and Ca and have lesser concentrations of Fe. The detection in the highland samples of a composition approaching that of terrestrial anorthosites, whose characteristic peculiarity is the exceptionally small percentage of Fe, attracts particular interest and attention. However, the mechanism of the development of both lunar and terrestrial anorthosites, and the scale of their distribution on the Moon remain unknown. In relation to the fact that "Lunokhod 2" was to study the transition between mare and highland, it was necessary to study the possibility of occurrences and areas of the anorthositic type. An analytic criterion, sufficiently clearly characterizing the two essentially different types of areas (mare and highland), was required to determine the scale of the transitional zone.

The investigation of the given data for the elemental composition of the 5
lunar surface shows that the most clear criterion is the percentage of Fe, which constitutes 3-5% in the highland regions and at the same time constitutes 12-15% Fe in the mares. If we compare the results of the analysis of the regolith, supplied by the stations "Luna 16" and "Luna 20" (Luna 20 value divided by Luna 16 value), assuming that they represent sufficiently typical mare and highland areas, then we can show that the concentrations of Mg and

Si differed by 1.1 times, Al by 1.4, Ca by 1.2, at the same time as the percentage of Fe differed by 2.4 times.

The relationships of the compositions of a series of elements to Fe also contains essential information. The significance of the value η, which we determined as the quotient from the division of the difference of the proportions to the half-sum of the concentration of specific elements in the regolith samples of "Luna 16 and 20", is presented in Table 2. It can be seen that the greatest range of the proportions is observed in the pair in which Fe enters into consideration.

The concentration of Fe was also taken as the principal analytic parameter, allowing us to confidently distinguish mare area from highland and allowing us to trace the transition from one type to the other in the "mare-highland" contact zone. In relation to this, for the modernized spectrometer "RIFMA" (1,2), particular attention was paid to the problem of the determination of the Fe concentration. For improvement of the effective excitation of Fe, tritium-titanium sources were substituted for tritium-zirconium ones.

Results of a Study of the Area by Means of the Spectrometer "RIFMA-M"

After the landing and initial movement of "Lunokhod 2", the surface at different points of its course was studied by means of the "RIFMA-M" spectrometer. The first measurement was conducted relatively close to the landing platform on the bank of a crater with a 40 meter diameter. The composition of the ground here appeared as follows: Si, 24 $\pm$ 4%; Ca, 8 $\pm$ 1%; Fe, 6.0 $\pm$ 0.6%; Al, 9 $\pm$ 1%; (remember that the measurements of "Lunokhod 1" in the Sea of Rains gave 10-12% Fe (1-3)). During movement of "Lunokhod 2" to the south, 6
a crater of 13 meters diameter, which was removed approximately 1.5 km. from the landing site, was exposed to investigation. The ground in this area appeared similar to the composition in the first studied area and suggested aluminous basalts. Thus, judging by the chemical composition of the surface, rocks in the region of the landing station could not be associated with the mare. As "Lunokhod 2" progressed to a hill in a southerly direction, the Fe content began to fall and had a value of 4.9 $\pm$ 0.4% at a distance of 4.5 km. from the landing site, while the Al percentage simultaneously rose to 11.5 $\pm$ 1.0%. This determination of the chemical composition was carried out close to a 2 km. diameter crater. By this time "Lunokhod 2" has already progressed 10 km. and was located in the limits of a hilly, slightly elevated

plain located to the southwest of the crater LeMonnier (already beyond the crater proper). It is known (6) from the type of topography that this area transitions from the Sea of Serenity to the highland massif of the Taurus Mountains. It is essential to note that the concentration ratio of Si to Fe in the region of greatest advance deep into the highland zone rose 1.5 times in comparison with a measurement in the landing area but the Al to Fe ratio rose to two times. Such a composition suggests terrestrial rocks of the anorthositic gabbro or gabbroic anorthosite types, and they are apparently widely distributed in the lunar highlands. 7

In later movements "Lunokhod 2" left the zone of hills and returned to the area of the crater LeMonnier. The measurements conducted here provided the composition of the ground, which was analogous to the composition in the landing area. In later movements "Lunokhod 2" studied the Straight Rille, located to the southeast of the landing site. A determination of the chemical composition of the surface was carried out in this region by the "RIFMA-M" spectrometer. The results of the analysis, carried out on the west and east slopes of this form, agree in the limits of experimental precision. Ca constitutes 8%, Fe constitutes 7.5 $\pm$ 0.9% on the western slope and 8.0 $\pm$ 1.0% on the eastern one. This exceeds by a small amount, the concentration of Fe in the flat part of the investigated region and is apparently related with the morphologic characteristics of the given surface region.

Discussion of the Results

Through the composition of the surface of the "Lunokhod 2" investigation, portions of the crater LeMonnier can be divided into three regions.

1. Results of the analysis accomplished in the flat portion of the bottom of the crater LeMonnier, gives us a basis to consider that the rocks in the landing area and the whole southern part of the crater are not typical of mares. The measured Fe values appeared around 6%, which is essentially a lower type of value for mare regions (10-12%). Meanwhile in topography and morphology (6) this region is most similar to the mare.

2. The second area (in the southwestern portion of the itinerary) is considerably different from the first. This region can be considered a variant of the highland area on the basis of bright surface tones, the abundance of chains of hills, the total upland surface and the small quantity of stones. Investigations of the chemical composition of the surface in the northern part of this lunar form showed that to the greatest degree the uppermost surface of the regolith here consists of rocks with very small (around 4%) 8
percentages of Fe and Al concentrations which increase in comparison with mare basalts.

3. The third region is an area in a zone of tectonic fracturing (Straight Rille), whose total extent is 16 km. with a width of some 100 meters. The Straight Rille is characterized by the fact that its slopes are covered with scattered stones; large (meter sized) stones are distinguished, evidently being outcrops of subsurface strata. During the movement of "Lunokhod 2" into the trench, a zone of large stones suddenly began, without a smooth transition. The movement at once became complicated, but we succeeded in crossing it to the vicinity of the fracture and produced an analysis of the composition of the surface. A clear increase in the Fe value on the slopes of the fault presents an interest.

Thus, as a result of the conducted study, data was produced, which indicates the detection of a gradual change of the chemical composition in the "mare-highland" transitional zone during the movement of "Lunokhod 2" along the surface of the crater LeMonnier to the highland by locating the self-propelled apparatus in the highland region, and during later movements to the bottom of a crater in an easterly direction; the surface in the transitional zone possesses intermediate characteristics.

Three different mechanisms can be drawn upon for the explanation of the detected surface characteristics: first, crystallization of rocks of an intermediate composition; second, horizontal transport of the material on the lunar surface; third, vertical transfer in the framework of a two-strata model. Results of the analyses and the undertaken task study of the geomorphologic setting in the work area of "Lunokhod 2" together allow us to assume at present a preference for a mechanism of horizontal transport for the material on the lunar surface.

The results of our study and the data from the Roentgen-fluorescence experiment on "Apollos 15 and 16" (7,8) give us the chance to form an opinion on the effectiveness of this mechanism, however, this problem lays outside of the framework of the present paper.

In conclusion, the authors wish to express their heartfelt indebtedness and thanks to Academicians A.P. Vinogradov and V.M. Tuchkevich for the great attention shown during the preparation and execution of the experiment and 9
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TABLE 1

A Comparison of the Composition of Certain Lunar and Terrestrial Rocks
(Values are in percent)

Element	"Luna 20" Anorthosite	Terrestrial Anorthosite	"Luna 20" Regolith Sample 2-1	"Luna 16" Regolith Sample	Ratio of Percentage of Elements of "Luna 16" Regolith to Their Percentage in the "Luna 20" Regolith
Mg	8.2	0.75	5.9	5.3	0.90
Al	10.1	15.0	11.4	8.1	0.71
Si	20.6	23.5	21.4	19.6	0.91
K	0.39	0.61	0.08	0.08	1.00
Ca	9.5	8.9	10.6	8.9	0.84
Fe	5.37	1.61	5.46	13.0	2.38

TABLE 2

The Value η (in Percent) for a Comparison of the Characteristic Elements of Lunar Rocks

Pair	Mg-Fe	Al-Fe	Si-Fe	Ca-Fe	Mg-Al	Si-Al	Ca-Al	Mg-Si	Al-Si	Al-Si
η (In percent)	90	108	90	95	22	25	16	3	11	7

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